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THE SUGAR-BEET LEAF-SPOT DISEASE AND ITS CONTROL BY DIRECT MEASURES[1]

By G. H. Coons, *Principal Pathologist*, Dewey Stewart, *Associate Pathologist*, and F. G. Larmer, *Assistant Pathologist, Office of Sugar Plants, Bureau of Plant Industry*

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THE DISEASE

For many years the sugar-beet industry in the United States has suffered great loss because of the Cercospora leaf-spot disease. The disease causes damage to a greater or less extent in the various sugar-beet areas, except where beets are grown under practically rainless summer conditions. In Ohio, Michigan, Indiana, and Minnesota the temperature conditions and the distribution of rainfall commonly operate to check the progress of the disease, and epidemics are infrequent if crop rotation is practiced. In other areas, such as Iowa, Nebraska, and northern Colorado, leaf spot seems somewhat more serious, and in the last decade several severe outbreaks of the disease have occurred. In the Arkansas Valley of southern Colorado the leaf-spot disease assumes major proportions and may be properly called the limiting factor in sugar-beet production for that region. For a 25-year period seasons without severe leaf-spot damage have been few, and the sugar percentages for the crop as shown by factory averages have often been 2 to 5 per cent lower than would have been expected on the basis of the soil and climatic conditions of that fertile area. The other western areas where beets are grown have been almost entirely free from leaf-spot losses, the climatic conditions serving to prevent widespread leaf-spot occurrence.

The leaf-spot disease, as its name implies, produces its damage through the production of spots upon the leaf blades and petioles of the beet. (Fig. 1.) In the case of beets grown for seed production the disease attacks various parts of the stalk and seed ball. In this way ovary walls and flower parts which make up the seed ball become infested with the causal agent of the disease, and, as will be seen later, this involvement plays a part in the dissemination of the fungus.

[1] The experimental work here reported has been carried on since 1925 in cooperation with the American Beet Sugar Co., Rocky Ford, Colo. Acknowledgment is made to A. W. Skuderna, superintendent of the research division, for advice and suggestions throughout the course of these tests. The dusting work in 1928 in commercial fields was carried out in cooperation with the American Beet Sugar Co. and with the Holly Sugar Corporation, Swink, Colo.

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The individual spot on the beet leaf results from the invasion of a germ tube from a spore of the parasitic fungus *Cercospora beticola* and the subsequent growth of the fungus in the tissues of the plant. Such a spot is usually about one-eighth of an inch in diameter and is frequently red bordered. When mature, the center of the spot becomes gray or white and is dotted with extremely black spots, hardly visible without a lens. These black dots are found, upon microscopic examination, to consist of gnarls of fungous threads. From each of these gnarls the fungus produces long slender spores in considerable number (e. g., 10 to 25). These spores, as will be explained, are dissemination organs of the fungus; and, if conditions favor sporulation, the spore production on leaves severely attacked may be so abundant as to give a frosty or silvery appearance to the leaves.

FIGURE 1.—Sugar-beet plant affected with leaf-spot disease

Commonly the attack progresses until the spots almost completely occupy the leaf blade. The petioles may become cankered. This heavy attack on the leaf blade results from a few primary infections which have furnished heavy crops of spores which have infected the mother leaf as well as near-by leaves.

Secondary effects also accompany this spotting of the leaves of the beet. The diseased leaves seem poisoned and lose their normal color, becoming pale or even yellowed. Frequently other fungi invade the spot begun by the leaf-spot organism; and the net result of this invasion, of the poisoning from the leaf-spot fungus, and of the drying of the leaves is to bring about the early death of the affected parts. Under conditions of severe leaf-spot attack, every green leaf may be dried up, the field appearing as if scorched. The

disease manifestations vary in the different fields, every stage being found, from the plants with a few scattering spots upon the leaves to plants with no living leaves except those unfolding at the apical bud. The advanced cases of the disease are usually at the primary infection centers, and the existence of such centers is attributable either to sources of infection, such as trash from a preceding crop, which have led to severe early infection, or to exceptionally favorable conditions for infection, such as would be afforded by low or poorly drained locations.

The attack of leaf spot does not kill the beet, and new leaf growth is produced to replace the dead tissue. If the conditions favor leaf spot, this new growth in turn succumbs to the disease, and this process of inception of the disease, its extension, and the subsequent death of the leaves occurs over and over as each new whorl of leaves develops.

The causal agent of this disease, *Cercospora beticola*, is introduced into the fields with the seed, or it may come from the tops of a previous crop of beets, since the fungus is able to live over winter on the diseased leaf-blades and petioles. It is not believed that the fungus grows and persists in the soil as a soil organism. During periods of epidemic the fungus has been demonstrated to be wind borne, and some fields may become diseased from spores blown from neighboring fields. Certain weeds have been shown to harbor the fungus, but the importance of these hosts and of wind dissemination from field to field has not yet been evaluated. Observation indicates that the carriage of the fungus on the seed or its persistence on the trash from a previous diseased crop insures the establishment of the disease in every field. The deleterious effects of successive beet crops or of maintaining too short a rotation give ample evidence of the importance of the tops from a previous crop as a source of disease. Leaf spot arising from a seed source manifests itself by attack upon the seed leaves or upon the earlier produced whorls of leaves. These attacks are commonly few in a field, since it is only occasionally that a seed ball is pulled above the ground by the seedling. Wet weather at the time of emergence of the seedlings favors infection. The sparse infection from a primary source in the spring, whether from the seed balls or from beet trash, may quickly become increased to much larger proportions if wet weather continues, or the disease may be checked temporarily by dry weather in April or May. The point to understand is that the inoculum is present each year, and, as weather conditions permit, the cycles of infection, spore production, and spread, which characterize diseases of this type, are repeated over and over again, each repetition bringing about more and more disease. Thus it is that these disease centers started here and there in a field like so many small fires, spread and rekindle themselves to start repeatedly new infections until the whole leaf surface of the field is consumed. Then new growth is put out by the plant. As soon as rain, humidity, and temperature conditions permit, infection of the new growth occurs, and the leaf killing is repeated.

The effect of this disease upon the beet can readily be inferred from the above description of its course under epidemic conditions. Its effect, naturally, varies with each plant, with each field, and, indeed, with each distinct area in a field. The destruction of leaf surface is met by the beet with prompt replacement of the destroyed area. This

replacement is made at the expense of the stored food reserves in the root. One of the common effects noted is the prompt depression in sugar content which follows leaf-spot attack. The low sugar percentages obtained by beet-sugar factories in epidemic years are clear evidence of this robbing of the beets of their sugar reserves. The second effect is the marked checking of growth which follows destruction of the leaf surface. The replacement processes turn the beet from growth to repair, and, accordingly, leaf-spot years are commonly years of disappointing tonnages.

The extent of tonnage depression has largely been overlooked, since no ready means of determining it has been available. The figures that are given later reveal something of this hidden loss for which leaf spot has been responsible. Leaf spot also causes increased loss to the factory and to the farmer by the waste involved in the so-called pineapple tops, as the crowns of beets whose leaves have been repeatedly destroyed by leaf spot are appropriately named. Severe leaf-spot attack is associated with low sugar percentages, which, in turn, indicate juices of low purity. Such juices present to the factory very formidable handling problems.

The leaf-spot disease in its manifold aspects becomes less puzzling if viewed in the light of the preceding statements. The freedom of certain areas in the far West from leaf-spot epidemics probably does not rest upon absence of the organism, but rather upon the checking of the disease by climatic conditions—rainfall distribution and unfavorable temperatures. The relation of frequent rainy periods and the attendant humid conditions becomes clear when it is remembered that the spores of the leaf-spot fungus require water for germination quite as much as do the seeds of higher plants. The leaf-spot fungus normally requires 10 to 13 days to complete its life cycle under optimum temperature conditions. Low temperatures lengthen the life cycle. Warm weather up to a certain point speeds up the action of the fungus, and leaf spot is worse in areas where fairly high summer temperatures with requisite rainfall prevail.

From the foregoing discussion it will be seen that the following control measures for leaf spot are warranted. Since diseased tops from a previous crop are a prolific source of spores of the causal fungus and the fungus may remain alive in the beet tops for longer than one year under certain conditions, it is strongly to be recommended that long periods between beet crops should be maintained. The fact that the fungus may be introduced sparsely with the seed, and under exceptionally favorable conditions may become epidemic in spite of the use of long rotations, should not be advanced as an excuse for following beets closely in the crop sequence. The heavy dosage of spores arising from the trash from the preceding crops plays so important a rôle in starting disease centers in the fields as to make it necessary to eliminate this important factor of the leaf-spot epidemics. This involves the planning of definite, long-time rotations. No other crop likely to be grown commercially in the beet areas is known to serve as a source of the sugar-beet leaf-spot fungus, the disease being restricted (so far as cultivated crops are concerned) to the beet and its near relatives.

As has been pointed out, the humidity relations influence the amount of leaf spot strongly. In the irrigated areas more careful use of irrigation water will do much to prevent leaf-spot depredations.

Frequent and sparing irrigations will eliminate the hazard that comes from the excessive application of water. Similarly, drainage plays its rôle in preventing excessive humidity in fields. Areas used for sugar beets should have good air drainage and exposure, so that rains of short duration may dry quickly, before the spores of the leaf-spot fungus cause infection. Fields that dry quickly may largely escape infection traceable to the slow drying of dew.

In the breeding work in the Office of Sugar Plants resistant varieties of sugar beets which will free farmers from the hazard attendant upon present stocks of sugar beets are being sought. Although progress is being made, it must be said that no variety has yet been found which can replace the present sorts.

There remains as a control measure for sugar-beet leaf spot the use of direct protective measures to prevent infection of the growing plants. For this purpose it is necessary to apply some fungicide to the leaves, in order to ward off the invading fungus.

Townsend [2] in 1914 gave results of spraying experiments extending over several seasons by which leaf spot was controlled by applications of Bordeaux mixture. He obtained marked increases in yields and increase in sugar percentage. He advised that spraying be begun as soon as leaf spot appeared. In spite of the success of these experiments, the use of Bordeaux mixture as a control measure has not become a general practice, even in areas where the leaf spot appeared and did damage nearly every season. In the Arkansas Valley, for example, only one farmer was found who followed a regular spraying program. His results, however, were entirely satisfactory.

EXPERIMENTS IN SPRAYING AND DUSTING

With the beginning of the writers' experimental work on sugar-beet leaf spot in 1925 at Rocky Ford, Colo., an attempt was made to determine the possibilities for control of leaf spot by spraying and by dusting with standard fungicides. Taking into consideration the likelihood of leaf spot occurring in epidemic form, the tests were planned to provide maximum protection to the plants by heading off the early phases of the infection, stamping out the small centers of infection before they were beyond control. The tests have now been continued over four years; and while tests over a longer period are desirable for such investigations, the results obtained thus far seem decisive enough to permit conclusions and recommendations as to applicability.

TESTS IN 1925

The experiments in 1925 were conducted on the West Ranch near Rocky Ford, Colo., and were located in a large field having a uniform stand. The field had previously grown crops of beets under a short rotation system. The plots were 24 rows wide and 1,089 feet long (approximately 1 acre). The arrangement of plots is shown in Table 1, and it will be noted that each treated plot had a check plot located beside it for comparison. The character of the treatment, the number of applications, and the dates when applied are shown in the table.

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[2] TOWNSEND, C. O. LEAF SPOT, A DISEASE OF THE SUGAR BEET. U. S. Dept. Agr. Farmers' Bul. 618, 18 p., illus. 1914. (Revised, 1922.)

TABLE 1.—*Results of spraying and dusting tests with sugar beets at Rocky Ford, Colo., in 1925*

[Area of each plot 1 acre]

Plot arrangement	Treatment	Applications	Dates of applications	Net yield [1]	Interpolated check values [2]	Gain (+) or loss (−) over check	Sugar [3]	Purity	Estimated sugar per acre [4]	Gain computed at $6.50 per ton of beets [5]
		Number		*Tons*		*Tons*	*Per cent*	*Per cent*	*Pounds*	*Dollars*
1	None	0		11.098			13.69	78.06	2,372	
2	Bordeaux spray	1	June 12	11.450	10.666	+0.784	13.23	78.52	2,379	5.10
3	do	2	June 12; July 9	11.618	10.235	+1.383	14.45	80.85	2,715	8.99
4	None	0		9.803			14.75	81.02	2,346	
5	Bordeaux spray	4	July 9; Aug. 11 and 27; Sept. 8	11.609	9.96	+1.649	13.78	77.42	2,480	10.72
6	Copper sulphate-lime dust	5	July 10 and 27; Aug. 10 and 26; Sept. 7	13.462	10.120	+3.342	14.55	80.48	3,153	21.72
7	None	0		10.279			14.07	80.74	2,335	
8	Bordeaux spray	4	July 9; Aug. 11 and 27; Sept. 8	10.611	10.345	+.266	14.93	82.66	2,619	1.73
9	Copper sulphate-lime dust	5	July 10 and 27; Aug. 10 and 26; Sept. 7	13.112	10.411	+2.701	15.40	82.94	3,350	17.56
10	None	0		10.477			14.39	80.46	2,426	
11	Copper sulphate-lime dust	3	Aug. 10 and 26; Sept. 7	9.873	10.300	−.427	14.01	81.98	2,268	−2.78
12	Bordeaux spray	3	Aug. 11 and 27; Sept. 8	11.173	10.124	+1.049	14.08	81.30	2,558	6.82
13	None [6]	0		9.948			12.47	79.36	1,969	

[1] Net yield determined by subtracting tare as determined for each load.

[2] Obtained by direct interpolation between adjacent check plots.

[3] Average of sugar determinations for each load as taken by factory and of laboratory determination of five samples from each plot.

[4] $\frac{\text{Percentage of sucrose} \times \text{coefficient of purity}}{100}$ = proportional value coefficient. This proportional value coefficient multiplied by the yield of beets per acre has furnished the estimated sugar return.

[5] Value of gain determined at flat tonnage rate and does not include any compensation for increased sugar percentage.

[6] Average of all check plots; Yield, 10.3210±0.153 tons; sugar percentage, 13.874±0.264; purity percentage, 79.93±0.37; estimated sugar quantity per acre, 2,290±55 pounds.

The crop history in relation to disease development may be briefly summarized. The first application of Bordeaux mixture to plots 2 and 3 was made at the time Paris green was being applied to the entire field in order to control the first brood of webworms (*Loxostege sticticalis* L.), which was causing considerable damage. Cercospora spots were so few at this time (June 12) that it required considerable searching to find one. On July 9 and 10 there was as yet no killing of leaves as a result of the disease, but noticeable spotting of leaves was evident. The last application of spray to plot 3 and the first applications of fungicide to plots 5, 6, 8, and 9 were made at this time. The amount of disease increased until August 8, when the condition properly could be called an epidemic, the greatest intensity being reached about August 20. The plants replaced the destroyed leaf surface to a certain extent after this attack, but a second onset of the disease rapidly followed, reaching its peak about September 10 to 15. The apparent amount of the disease was decreasing again at the time harvest was started, September 25.

During a rainy period that started July 19 and continued with little interruption until August 4, the field was wet to a greater or less extent practically every day of this period. Because of the soft condition of the field the heavy sprayer could not be operated, thus interfering with the scheduled set of applications. No difficulty was experienced in making the scheduled dust application on July 27.

The Bordeaux mixture used was the standard 4–4-50 formula, and approximately 100 gallons were used to the acre. The applications were made with a 100-gallon traction sprayer at a pressure of 100 pounds. Excellent coverage was obtained by use of three nozzles per row. The dust applications were made with a traction duster which treated four rows at a time, two nozzles being used to the row. The dust used was a factory-mixed product, consisting of approximately 20 per cent monohydrated copper sulphate and 80 per cent hydrated lime.

As already mentioned, the tests were begun at the time of the standard Paris green spray to control webworms. Four pounds of arsenate of lead was included in each 100 gallons of fungicide on the subsequent applications, and 8 pounds of arsenate of lead was added to each 100 pounds of copper sulphate-lime dust. These were precautionary measures intended to control the second brood of webworms. The webworms did not appear to any serious extent, and no insecticide treatment was given the check plots, because it was felt that more injury would result to the check plots during the application than was being caused by the few webworms present. There was no webworm injury on the test as a whole, the slight early injury to the checks from the unpoisoned larvae being completely outgrown.

The field was harvested in 24-row plots, weights and sugar percentages being obtained from the regular factory weight and analysis reports. The percentage of purity given represents the average of five samples (10 beets each) collected from each plot at harvest time. The sugar determinations from this series of samples were averaged with the sugar samples taken at the time of delivery of the beets; thus eight determinations were used for each plot for sugar percentages. The gross yield of the plots was reduced to net yield by subtracting the percentage of tare as determined for each load delivered. The estimated sugar per plot was determined on the basis of the sugar

percentage and apparent purity.[3] The value per acre to the grower has been computed at a flat rate of $6.50 per ton and does not take into consideration any increased compensation for increase in sugar percentage. These figures are given merely as a convenient measure for determining how costs of treatment are offset by returns in tonnage in the various treatments. The data for the plots are also shown in Figure 2.

Study of the data given in Table 1 shows that with the disease conditions existing in 1925 early applications of Bordeaux mixture served to check infection and gave an increase in tonnage, two applications (one June 12 and the second July 9) being more effective

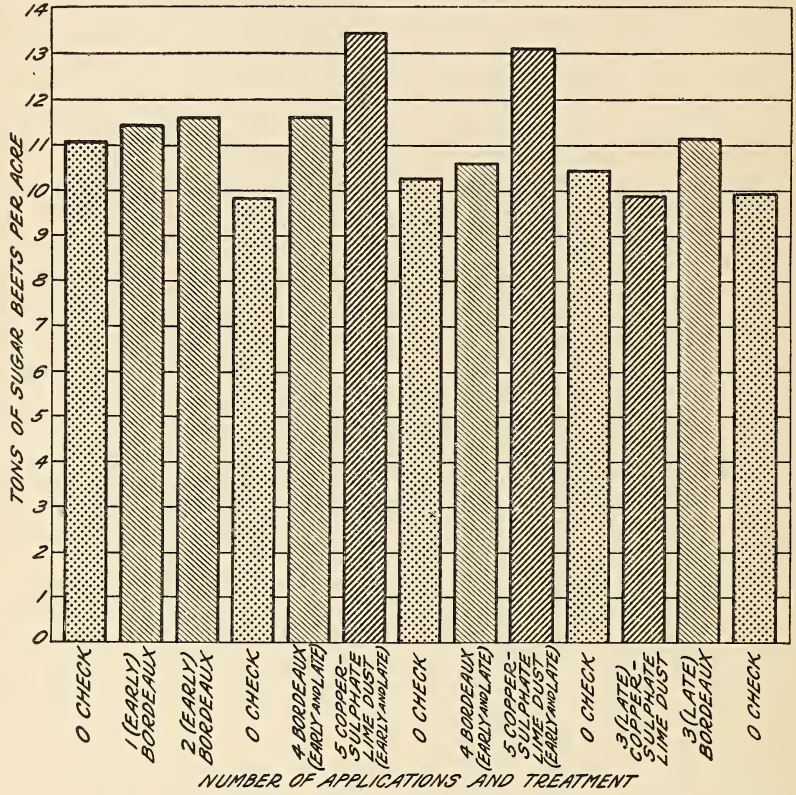

FIGURE 2.—Comparison of tonnages obtained from dusted and sprayed plots with those obtained from adjacent untreated plots. (Compare with Table 1)

than the single earlier application. The significance of this result in relation to liquid applications of Paris green for webworm control which frequently need to be given at about this period should be emphasized. Since in years of webworm outbreak many fields are sprayed with an insecticide, the addition of lime and copper sulphate in proper proportions makes possible the securing of valuable fungicidal action with only the additional cost of materials (about 35 to 75 cents per acre).

Four applications of Bordeaux mixture beginning July 9 and continuing at about 2-week intervals, with, however, the July 27 appli-

[3] See footnote 4 to Table 1.

cation omitted, in two tests gave only mediocre increase in yield over the yield of the check plots.

The copper sulphate-lime dusts, timed approximately with the above Bordeaux applications, but with the July 27 applications included, gave the best yields of all, and the results obtained from the individual plots are in excellent agreement. A comparison of the results obtained on the plots dusted five times and those obtained from the plots sprayed four times indicate the critical situation in leaf-spot control as existing about July 27. As has been explained, at this period the weather conditions were extremely rainy, and leaf-spot infection was at its height. The fact that the sprayer with its heavy load of liquid spray could not be operated in the field, whereas the lighter duster could be used, points out an important consideration in the protection of the plants. Furthermore, it should be mentioned that the readily available water supply for making Bordeaux mixture in this region is from the open irrigation ditches; and this water, if used without special attention to settling and clearing, because of its muddy condition and the floating organic matter, proved very troublesome in clogging nozzles and thus delaying operations.

The plots receiving three late dust applications (begun August 10) yielded 0.427 ton less than the check, whereas plots receiving three late Bordeaux applications showed a gain over the yield of the check. The indications are that the greatest returns are to be expected by prevention of extension of initial infection stages rather than by the control of the disease after it reaches epidemic form. Seasons vary greatly in their effects upon leaf-spot prevalence, but this general deduction from the 1925 test, in line with spraying and dusting experience with other crops, seems warranted.

TESTS IN 1926 AND 1927

The general plan of work in the seasons of 1926 and 1927 was very similar to that in 1925, but the fields available permitted the laying out of the plots in five replications in which five spray and five dust applications, spaced about two weeks apart, could be compared with the results of three sets of applications of the same types begun later in the season. The arrangement of plots within each series was as given in Table 2, and series B, C, D, and E repeated the order of series A.

TABLE 2.—*Results of spraying and dusting tests with sugar beets at Rocky Ford, Colo., in 1926*

[Experiments laid out in 8-row plots approximately 500 feet long with five replications; data taken on a fair, sample area, one eighty-second acre in size, from each plot,[1] rows 3, 4, 5, and 6 of each plot being harvested. Applications were begun July 12 and were given at 2-week intervals]

Treatment	Applications	Yield of sample plots					Average yield	Average sugar	Computed beet yield per acre
		A	B	C	D	E			
	Number	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Pounds*	*Per cent*	*Tons*
Check	0	309	304	375	299	258	[2]	[2]	[2]
Bordeaux mixture	5	383	275	388	300	288	327±16	15. 78±0. 49	13. 36
Copper sulphate-lime dust	5	461	288	329	306	344	346±21	15. 22± . 54	14. 13
Check	0	387	286	347	339	357	343±11. 1	16. 02± . 39	13. 32
Bordeaux mixture	3	402	254	427	338	353	355±20	14. 62± . 51	14. 50
Copper sulphate-lime dust	3	394	275	458	315	355	359±21	15. 08± . 43	14. 66

[1] This strip of field was chosen on account of being fairly uniform in stand.
[2] Combined with other check plots.

There was so little disease in 1926 that the data have little significance so far as disease control is concerned. Fields remained entirely green until frost, and there was no evidence that the disease factor influenced either yield or sugar percentage. Sample areas consisting of rows 3, 4, 5, and 6 of each plot were selected along a strip of the field where the stand seemed most uniform for taking data. The figures, as will be seen from the probable errors[4] given, are not significant, although they might be interpreted to show slight trends in favor of the late applications.

The 1927 season was one in which leaf spot did not appear in any noticeable amount until September. Although considerable rainfall occurred in August, the exceedingly cool weather accompanying it effectively slowed up any epidemic conditions. The beets grew normally until the middle of September without noticeable loss of leaf surface from leaf spot. During September leaf spot began to be evident, but at no time did it reach the stage where excessive leaf scorching occurred. The sprayed and dusted plots were well protected from disease attack and were in marked contrast to the check plots. The actual protecting value of the applications was evident in field inspections, the check plots being yellowed and on the verge of serious disease, while the treated plots were green and well protected. Preliminary samplings of the plots on October 1 showed slight difference in sugar percentage in favor of the sprayed and dusted plots. Weather conditions of the fall of 1927 were exceptionally favorable for sugar storage by the crop and effectively checked the late-starting outbreak of the disease. The differences in the plots were largely compensated for by the increases made by the fall growth.

The results obtained as shown in Table 3 are from data obtained by harvesting the 8-row plots. The stand, because of lack of irrigation water early in the season, was not so uniform as would be desirable in such a test, and the high range of variation destroyed much of the significance of the figures. At best one might conclude that there was a slight trend in increased sugar percentage from the treatment, with no marked differences in tonnage figures.

TABLE 3.—*Results of spraying and dusting tests with sugar beets at Rocky Ford, Colo., in 1927*

[Experiment laid out in 8-row plots 470 feet long, with five replications, and harvested Nov. 2, 1927]

Treatment	Applications	Weight of beets per 0.14-acre plot					Average yield	Average sugar [a]	Computed beet yield per acre
		A	B	C	D	E			
	Number	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Lbs.*	*Pounds*	*Per cent*	*Tons*
Check	0	4,096	4,542	3,801	3,949	4,454	[b]	[b]	[b]
Bordeaux mixture	5	4,186	4,292	3,450	3,562	4,439	3,986±135	16.18±0.49	14.23
Copper sulphate-lime dust	5	3,960	5,204	2,973	4,413	4,234	4,157±243	16.74± .50	14.85
Check	0	4,253	4,675	4,388	3,919	3,912	4,199± 65	16.05± .28	15.00
Bordeaux mixture	3	3,332	3,748	4,386	4,399	3,589	3,891±145	16.46± .07	13.90
Copper sulphate-lime dust	3	4,070	4,038	3,958	3,753	4,171	3,998± 51	15.9 ± .23	14.28

[a] Data computed from 5 samples from each treatment, except checks, in which samples from 10 plots were used.

[b] Combined with other check plots.

[4] Probable error was computed by Bessel's formula, $PE=0.6745\sqrt{\frac{\Sigma d^2}{n(n-1)}}$.

These two seasons are included in the report on this work on leaf-spot control to show the vicissitudes of climatic influences and disease relationships in the Arkansas Valley and to indicate that no gains in sugar percentage or tonnage are to be expected as a result of the so-called "stimulating action of copper fungicide." The 1927 season left no doubt in the mind of anyone observing the plot as to the effectiveness of the applications in checking leaf-spot development. The lack of contrast in the figures as presented reflects the rather mild leaf-spot attack which developed in the fall.

TESTS IN 1928

Experimental work in 1928 consisted of two types of test: (1) A continuation of the 1926 and 1927 tests, and (2) tests on farmers' fields with copper sulphate-lime dusts.

TABLE 4.—*Results of spraying and dusting tests with sugar beets at the experimental farm at Rocky Ford, Colo., in 1928*

[Results are given as averages of duplicate 8-row plots. The total length of each plot was 750 feet, and every fourth plot was untreated]

Treatment	Material used	Applications	Average yield	Interpolated check values [1]	Gain over interpolated check values	Average sugar	Average purity	Estimated sugar per acre [2]	Gain computed at $6.50 per ton of beets
		Number	*Tons*	*Tons*	*Tons*	*Per cent*	*Per cent*	*Lbs.*	*Dollars*
None	None	0	9.766			15.01	79.87	2,341	
Dust (copper sulphate and lime).	Machine mixed, 20–80.	4	10.819	9.949	0.870	15.44	80.92	2,703	5.56
Liquid spray (Bordeaux mixture).	4–4–50	4	10.925	10.041	.884	15.04	82.33	2,705	5.74
Dust (copper sulphate and lime).	Factory mixed, 20–80.	4	11.846	10.132	1.714	14.74	80.59	2,814	11.20
None	None	0	10.316			14.57	79.15	2,379	
Dust (copper sulphate and lime).	Machine mixed, 20–80.	3	10.973	10.297	.676	14.60	78.68	2,521	4.49
Liquid spray (Bordeaux mixture).	4–4–50	3	10.831	10.288	.543	14.89	78.73	2,539	3.52
Dust (copper sulphate and lime).	Factory mixed, 20–80.	3	10.330	10.279	.051	14.89	79.07	2,432	[3] .33
None [4]	None	0	10.260			14.82	79.64	2,422	

[1] Determined by direct interpolation between nearest check plots.

[2] The estimated sugar per acre was obtained by multiplying yield in pounds by the proportional value coefficient: $\frac{\text{Percentage of sucrose} \times \text{coefficient of purity}}{100}$ = proportional value coefficient.

[3] The plots in this series were seriously affected by Rhizoctonia root rot, which very markedly reduced the yields.

[4] Average of all check plots: Yield, 10.10 ± 0.16 tons; sugar percentage, 14.81 ± 0.13; purity percentage, 79.49 ± 0.25; estimated sugar, yield per acre, $2,374 \pm 23$ pounds.

TESTS AT EXPERIMENT FARM

In the first type of work, plots consisting of eight rows 750 feet long were laid out in a field at the experimental farm, Rocky Ford, Colo., the order being that given in Table 4. For direct comparison of the traction duster with the autoduster, as used in the field work on farmers' fields, plots dusted with the two types of machine were included in this test. Otherwise the methods of dust and spray application followed the plan of previous seasons. The treatments were made in duplicate series, but each plot was harvested in five equal sections. The results, however, are given here in condensed form,

since this particular field was severely injured twice by hail in August, and what gave every promise of being an excellent test was made inconclusive. The figures obtained show definite trends in favor of treatment to control the leaf disease, but the differences upon statistical analysis are not significant. It will be noted that in every case increased tonnage was obtained as a result of treatment, and in all cases the estimated quantity of the sugar per acre was greater in the dusted and sprayed plots than in the check plots. The experience of 1928 with this field does indicate in the low tonnage obtained in this field as a whole the marked injury that loss of leaf surface entails, whether it be loss from leaf spot or from hail. The field before the hail period gave marked ocular evidence of the control of leaf spot being accomplished, and the differences, though slight, are believed to be trustworthy indications of the results beginning to show in the field at the time of hail injury.

TESTS IN FARMERS' FIELDS

The experiences in 1925 and 1927 having shown the value of dusting for leaf-spot control, experiments were conducted in 1928 on a large

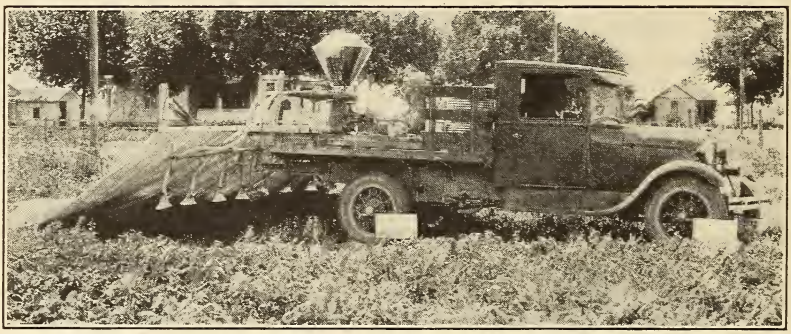

FIGURE 3.—Gasoline-driven duster mounted on an autotruck, as used in the 1928 experiments. Shields placed in front of the wheels turn back the beet foliage

scale in order to test the dusting method over such an extensive area in the Arkansas Valley that leaf-spot conditions would surely be met. In order to do this, it was necessary to devise a dusting outfit capable of carrying its materials in quantity, which would quickly and effectively apply the fungicidal dust, and which would enable the operators to treat fields in the Arkansas Valley 110 miles apart.

For this purpose a gasoline-driven duster of the "self-mixer" type was mounted upon an autotruck having a tread of 56 inches. (Fig. 3.) It was found to work well in fields planted with the customary 20-inch spacing used for beet rows. It could not be used in fields with 22-inch spacing of rows, and in fields where 24-inch spacing was employed it could be used only when the plants were small. In driving the truck down the beet rows it was essential to start operations with the left wheels in the so-called "guess-row"—that is, the truck must be run in the same series of rows as are put in by each successive bout of the planter in order to follow the minor variations in the rows. As the plants became larger shields were placed in front of the wheels in order to turn back the leaves to prevent damage. The truck was

equipped with low-speed transmission gears; but since a speed of 5 to 7 miles an hour can be maintained it is probable that these are not absolutely essential. The truck did no more damage in turning in a field than horses do at cultivating time, and little difficulty was

FIGURE 4.—Autotruck duster operating in a field of sugar beets

FIGURE 5.—Cloud of dust gradually settling in a field after the operation of the duster

FIGURE 6.—A dusted strip in a sugar-beet field

experienced in making the applications. The fields must be fairly dry to afford traction. The wide lateral ditches commonly found in large fields were crossed by placing planks where necessary or by shoveling dirt away from the banks. The duster treated eight rows at a time, with one nozzle to the row. (Figs. 4, 5, and 6.)

The materials used in this work were monohydrated copper sulphate, which was weighed out in 12½-pound lots, and hydrated lime, which was obtained in 50-pound sacks. The lime was placed in the hopper of the duster and the copper sulphate placed on top of the lime. The lid of the hopper was then clamped in place and the machine started. A powerful agitator in the hopper brought about efficient mixing of the dusts. As will be seen, approximately a 20-80 dust was thus applied to the fields, and the rate of delivery was adjusted so that approximately 35 pounds were used for an acre at each application.

Many of the fields used in this test were fortunate in escaping the rather general hail injury. Out of 17 farmers' fields chosen for this work 11 escaped injury and furnished harvest records. The fields chosen were from the areas of the valley where leaf spot had been a severe problem in previous years, and 7 of the fields had a history of severe leaf-spot losses in the previous year, beets following beets on these fields. In every case leaf spot was present as an infestation of more or less severity before dusting was started, and it is believed that the method of control of leaf spot had a trial under severe conditions during this test.

The dusted area in each field consisted of either 24 or 32 rows chosen in a part of the field having uniform stand and as uniform soil conditions as possible. In only one case (field No. 3) did marked differences in soil fertility interfere with the fairness of the test. In this field, plot 4 (the check) showed beet foliage noticeably higher than that in the adjacent areas. Mr. Weihing, the owner of the field, attributed the difference to the fact that for two years he had piled bean straw on the upper end of this area, and although an attempt was made to clean it up, the job was not well done. There was evidence of strong differences in soil fertility in favor of the check plots in this field. Leaf spot did but little damage, and the inclusion of results from this plot does not seriously affect the marked significance of the results with other fields or with the other plot of this field.

Taking the fields as a whole, the average tonnage on the dusted plots was 16.078 tons per acre, while the adjacent checks had an average of 14.257 tons per acre, with odds of significance of 9,999 to 1 (Student's method).[5] The average sugar percentage for all the dusted plots was 14.78, while the adjacent check plots averaged 14.14, with odds of 499 to 1 against a difference as great as this occurring due to chance alone. The average purity of the dusted plots was 76.52 per cent, and the average purity of the adjacent check plots was 75.34. The odds in this case were 499 to 1. The estimated sugar productions per acre for all dusted plots was 3,636.8 pounds, while the adjacent check plots yielded an average of 3,025 pounds, making an average gain of approximately 612 pounds per acre in favor of the treatment. The odds in this case were 9,999 to 1 against a difference as great as this due to chance alone.

It will be seen from inspection of Table 5 and Figure 7 that in the season of 1928 the marked increase from dusting work was reflected in the tonnage, and every plot but 2 of the 17 in these 11 fields showed

[5] THE PROBABLE ERROR OF A MEAN. By Student. Biometrica 6 : 1–25, illus. 1908.

a gain in tonnage from the protective treatment. The two exceptions, fields Nos. 3 and 11, showed a drop in tonnage below the check of 0.128 and 0.337 ton, respectively. The general increase in the tonnage shown, taking into consideration that the leaf-spot attack in some fields was outgrown and the loss was confined to the lower leaves, reveals that leaf spot in its effect on tonnage has been levying a heavy toll year after year in the Arkansas Valley district. This loss has been seen in those years when the attack has come in severe form before the plants were half grown, but for lack of any basis for comparison this general wasting effect of leaf spot has been unrecognized in the years of moderate attack or of late-occurring epidemics.

FIGURE 7.—Comparison of tonnages obtained from dusted and from untreated plots in the 1928 experiments. (Compare with Table 5)

The sugar percentage for the dusted plots was greater than for the adjacent check in all but 4 of the 17 pairs compared, but the gains in sugar in the 1928 season are probably far below those to be obtained in a season when storage of sugar and checking of leaf spot is not brought about by cool fall conditions. Coincident with the gain in sugar percentage in the beets is to be seen a rather consistent superiority of the purities of the samples from the dusted plots over the purities obtained from the check-plot samples. Only 3 of the 17 plots showed higher purities in the checks than in the dusted areas. In the majority of cases the purity increase was decisive.

TABLE 5.—*Results in Colorado, in 1928, of using an autotruck duster on 24-row strips in commercial beet fields, the adjacent 24 rows serving as check plots*

[The harvest records were taken from factory weights and tares. Sugar and purity percentages are from five samples of 10 beets each from each plot]

Field No.	Name of owner	Location	Applications	Area of plot	Yield per acre	Sugar	Purity	Estimated sugar per acre	Acre returns at $6.50 per ton of beets	Initial infection	Dates of applications	Severity of disease in checks at close of season
			Number	*Acres*	*Tons*	*Per cent*	*Per cent*	*Pounds*	*Dollars*			
1	S. C. Geringer	Nyberg	2	1.203	11.420	16.64	76.67	2,914	74.23	Severe	Aug. 6 and 28	
			0	1.203	9.969	16.02	75.93	2,425	64.80	do		Considerable.
2 [1]	R. Call	Newdale	0	.431	19.08	13.16	74.99	3,766	124.02	Slight		Severe.
			3	.410	20.995	15.46	77.67	5,042	136.47	do	July 24; Aug. 8 and 27	
			0	.389	19.199	13.81	74.42	3,946	124.79	do		Do.
			3	.369	21.003	14.13	75.55	4,484	136.50	do	July 24; Aug. 8 and 27	
			0	.355	18.502	13.30	74.23	3,653	120.26	do		Do.
3 [2]	H. J. Weihing	Newdale	2	.592	17.937	15.5	[3] 77	[3] 4,281	116.59	Scarce	July 30; Aug. 16 and 24	
			0	.592	16.868	15.4	77.53	4,028	109.64	do		Practically no injury.
			3	.592	17.854	16.13	80.66	4,646	116.05	do	July 30; Aug. 16 and 24	
			0	.592	17.982	15.61	79.37	4,456	116.88	do		Do.
4 [4]	William Malott	Roberta	2	.629	19.228	14.84	76.85	4,386	124.98	Slight	July 31; Aug. 24	
			0	.629	16.151	14.77	78.12	3,727	104.98	do		Considerable killing of lower leaves.
5	C. Malott	Roberta	0	1.194	9.031	16.16	79.01	2,306	58.70	do		Slight.
			3	1.194	10.345	15.48	79.55	2,548	67.24	do	July 30; Aug. 9 and 29	
			0	1.194	9.071	15.47	75.76	2,127	58.96	do		Do.
			3	1.194	9.516	17.29	80.91	2,662	61.85	do	July 30; Aug. 9 and 29	
			0	1.194	9.215	16.18	77.65	2,316	59.90	do		Do.
6	S. Bingham	Roberta	2	1.33	12.732	14.7	79.27	2,967	82.76	Considerable.	Aug. 6 and 25	
			0	1.33	10.405	14.9	78.14	2,423	67.63	do		Severe.
7	T. Yogami	Swink	2	1.092	17.161	16.36	78.77	4,423	111.55	Heavy	Aug. 8 and 27	
			0	1.092	14.166	16.58	78.44	3,684	92.08	do		Heavy.
			3	1.092	18.359	17.73	81.19	5,285	119.33	do	July 23; Aug. 8 and 27	
			0	1.092	13.522	16.15	78.76	3,440	87.89	do		Do.
8	S. Lee	Melina	3	1.148	16.081	15.36	76.79	3,795	104.53	do	Aug. 1, 15, and 31	
			0	1.148	15.339	13.43	74.80	3,082	99.70	do		Moderately heavy.

9	G. W. Rountree	Los Animas	3	.558	18.873	13.09	73.59	3,636	122.67	Slight	Aug. 2, 15, and 31	Very severe.
			0	.558	16.117	12.18	71.91	2,823	104.76	do		
			4	.558	19.623	12.44	73.31	3,579	127.55	do	July 17; Aug. 2, 15, and 31	Do.
			0	.558	17.083	11.56	71.15	2,810	111.04	do		
10 [5]	J. Bridges	May Valley	4	1.506	15.406	10.28	67.08	2,124	100.14	Severe	July 22; Aug. 7, 23; Sept. 14	Severe.
			0	1.506	12.546	9.46	64.92	1,541	81.55	do		
11 [6]	W. J. Buckston	Wiley	4	1.22	14.082	12 43	71.79	2,513	91.53	do	July 15; Aug. 2, 14, and 30	Moderate.
			0	1.22	12.978	12.86	73.75	2,462	84.36	do		
			3	1.33	12.722	13.46	74.23	2,542	82.69	do	Aug. 2, 14, and 30	Do.
			0	1.33	13.059	12.76	73.89	2,463	84.88	do		

[1] In field No. 2, 32 rows were used instead of 24 rows.

[2] Sugar samples were lost; the data are based on the load samples, the percentage of purity being estimated. Plot No. 4 of this field showed marked difference in soil fertility. At no time was leaf spot severe, this field being as free from disease as any in the district.

[3] Estimated.

[4] Gradual killing of leaves from August to harvest time.

[5] The first application was made when the field was badly blighted; control was moderately effective.

[6] Plot 1 of this field was piled 6 days before delivery to the factory; the other plots were delivered immediately.

The differences in yield, sugar percentage, and purities are all reflected in the figures obtained for estimated sugar per acre, and in the 1928 test every plot showed increase in sugar production. Two of the plots (field No. 11) did not show a large increase, but in the case of the other 15 the gains of the dusted plots over the adjacent checks are significant.

DISCUSSION

From the foregoing presentation of the situation in leaf-spot control as met with in the Arkansas Valley, the opinion of the writers relative to the value of leaf-spot control by spraying and dusting in this area can readily be seen. Were the situation in sugar-beet production in this area less pressing, a more extended period of experimentation would be preferable before recommending that direct control practices be given commercial trial. The writers are convinced that both spraying with Bordeaux mixture and dusting with copper sulphate-lime dusts are effective in leaf-spot control if begun in time and continued long enough to afford protection for the successive whorls of leaves. The problem to be solved is rather the economic one, which concerns itself with the frequency of leaf-spot outbreaks, the aggregate costs to the farmers and factories, and the actual costs and technic of large-scale undertaking of direct-control measures. The results to date, therefore, are being given as a progress report, from which the commercial interests and farmers concerned, who know from their experiences the seriousness of the leaf-spot problem, may make their own decision as to the desirability of crop protection by either of the two direct methods that have been found effective.

The chief argument that can be advanced in favor of liquid applications for this district is that the cost of the Bordeaux mixture is less than the cost of dust applications. On the basis of costs for potato spraying, the cost for four Bordeaux applications may be estimated at about $5 an acre.

In the writers' experience, spraying with Bordeaux mixture has proved to be onerous, and in one season (1925) it could not be done at the critical period. The difficulties of securing a water supply suitable for making the spray mixture have been mentioned. The fact that a spraying program has not already been adopted in this area where leaf spot has been so serious indicates the general reaction of beet farmers toward this method of control. Many have stated that in view of the large acreage grown by the individual farmer, any attempt to urge the application of Bordeaux mixture would probably cause the farmer to turn from beet growing to some other line of agriculture.

It should be pointed out, however, that where an acreage is to receive sprays containing Paris green or arsenate of lead for webworm control, the addition of copper sulphate and lime in proper proportions to make a Bordeaux spray will probably give returns far in excess of the small cost of these chemicals. On the other hand, where equipment for dusting is available, emergency dusts for webworm control can quickly be applied, and there is evidence that as insecticides these are as effective as liquid applications.[6]

In the case of dust applications, decision as to the type of machine to be used is probably dependent upon the method used in carrying out the dusting program. If the work is to be done by the individual farmer, the horse-drawn traction duster, owned on the farm and used

[6] Oral communication from A. W. Skuderna.

by the farmer or by a group of farmers, provides the cheaper outfit, and this type of machine in the writers' tests has been effective. If the work is to be done by the factory as a service chargeable to the crop, the autotruck duster as developed in this experimental work may be found useful. While it is probable that without much difficulty or loss of traction power from the truck the dusting machine could be operated from a power take-off from the motive power of the truck, no such machines were available for use, and the experience reported has been entirely with a duster operated by an auxiliary gasoline engine. The duster formed a unit which could be placed on a commercial truck, and at the close of the dusting season the duster could be removed, thus freeing the truck for other work. Experiments have not been carried far enough to permit a decision as to the type of machine best suited for the conditions.

The comparatively small scale of the individual treatments has not permitted accurate determination of the cost of dusting sugar beets. The only definite figures that may be given are the costs of the material used, but these figures probably represent a fairly high estimate, since with larger use of the chemicals economies in this regard probably can be effected. The monohydrated copper sulphate as purchased for this experiment cost approximately $15 per hundred pounds delivered, and the lime used was ordinary finishing lime which cost $1.50 per hundred pounds. Used at the rate of 20 pounds of copper sulphate to 80 pounds of lime, 100 pounds of the dust cost $4.20.

In this experimental work the mixing was done by the machine, the method of making the dust being as follows: A 50-pound sack of lime was placed in the hopper of the machine and 12½ pounds of copper sulphate (monohydrated) were then added. The hopper was closed and the machine started. The agitator with which this machine was provided quickly brought about even mixing of the two ingredients. Mixtures can also be bought already prepared, or the base materials may be mixed at some central plant without much increase in cost.

Approximately 35 pounds of the above-mentioned dust was used per acre at each application, thus making the cost about $1.50 per application for materials. The cost per acre for the season for the fungicide ranged from $4.50 to $6, depending upon the number of applications. The time taken to cover an acre with the autoduster can not be given. In the experimental work the period spent in the field applying the dusts was the least of the time factors concerned. Probably an autotruck duster could cover from 4 to 5 acres an hour as a minimum. In fields with long rows, and with a minimum of time lost in crossing lateral ditches, the speed of application of the fungicide would be increased. The cost of application may roughly be estimated at 50 cents an acre per application, but this figure is probably high. The total costs of a season's dusting per acre may be estimated at from $6 to $8, with the reservation that these figures are high and probably can be reduced in actual practice. The following sources of economies may be pointed out: (1) The costs of base materials for the dusts will be reduced when larger quantities of copper sulphate are purchased and when the freight rates are based upon carload shipments. The cost of the lime can be considerably reduced if factory lime, which exists in large quantities and is at present largely a waste product, is utilized in part as a filler for the dust mixture. (2) With the inauguration of a definite dusting program, the layout of the fields

can be so arranged as to allow adequate areas at the ends of the rows for turning, as well as to allow for more easily traversed lateral ditches. (3) The machine used in the 1928 tests dusted 8 rows at one time, but there seems to be no mechanical obstacle to increasing the number of nozzles to 12, thus increasing the area covered at one time from 8 to 12 rows.

Judging from their experience, the writers would point out that for the seasons free from leaf-spot attack, such as 1926, no gains from treatment are to be expected, and in the seasons of light or late attack, such as 1927, the results will probably just about pay the cost of protection. Present knowledge of leaf-spot epidemiology does not permit forecasting the years of heavy leaf-spot occurrence, and plant protection of the type discussed must be viewed as a form of crop insurance. From the experience of the last 20 years in the Arkansas Valley, in which all except 4 or 5 have been years of heavy leaf-spot toll, such insurance seems warranted. In many other areas, such as Michigan, for example, the type of plant protection here described will probably be most serviceable as an emergency control measure.

Taking into consideration the varied conditions met with in these experimental plots, which were portions of farmers' fields scattered over a territory in the Arkansas Valley extending 40 miles north of Rocky Ford and 70 miles south, and also taking into consideration the fact that great variation in the time and the extent of leaf-spot outbreak were encountered, the results of 1928 are very consistent. It is believed that these results may be taken as a fairly safe index of benefits derivable from adequate protection of the beet crop from leaf-spot attack. These results may also serve as a guide to the proper procedure as to dusting methods for commercial interests, as well as for farmers who are concerned in controlling leaf-spot outbreaks.

SUMMARY

A brief discussion of the rôle of the fungus *Cercospora beticola* in causing leaf-spot epidemics is given, and the relation of various climatic factors to the occurrence of these epidemics is outlined.

General control measures of value in preventing outbreaks of leaf spot are briefly discussed. Of these, crop rotation to eliminate the danger from diseased tops of previous crops is the most important.

Direct control measures, consisting of sprays and dusts applied at various times, were tested in 1925, 1926, 1927, and 1928. Five applications of dust in 1925 gave the best control of leaf spot that year. Tests in 1926 and 1927, years in which leaf-spot damage was slight, showed no significant gains from either dusting or spraying. In 1928, copper sulphate-lime dusts applied by a gasoline-driven duster mounted upon an autotruck showed in tests carried on in commercial fields that in a year of leaf-spot epidemic three or more applications of dusts at the rate of 35 pounds per acre per application gave, on an average, increased tonnage, sugar percentage, purity, and estimated sugar production far more than enough to offset the cost of treatment. The results for 1928 are believed to furnish a fairly safe index of the returns to be expected from this method of leaf-spot control.

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